Baseline composition and microbial quality assessment of raw milk from endemic small ruminants and *Maghrebi* camels in the oasis area of Tunisia

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Abstract

The milk quality and characteristics of the local *Gharbi* sheep and autochthonous goat population were studied and compared to those of the local *Maghrebi* camel. Milk samples from 378 lactating animals raised in the Tunisian oasis region were obtained and processed for various physicochemical compositions (pH, density, acidity, dry matter, fat, protein, lactose, casein, ash, and casein-protein ratio), mineral concentrations (Ca, P, Na, and K), and bacteriological properties (total mesophilic aerobic bacteria (TMAB), total coliform count (TCC), lactic acid bacteria (LAB), sulfite-reducing *Clostridium* (CSR), yeast and molds (Y/M), *Staphylococcus aureus* (*S. aureus*), *Escherichia coli* (*E. coli*), and *Salmonella*) using standard methods. Milk from sheep breeds had a higher average of all physical parameters (pH, density, and dornic acidity) than milk from goat species. The sheep population produced milk with a similar pH to the camel population, but with a higher density and acidity content. The pH and acidity were higher in Neggas than in goat species, while density was similar in both. For chemical composition, the results showed significant heterogeneity in milk content across all species. Except for the casein-protein ratio, which favors goat species, the analysis indicates that sheep species were superior to populations of goats and camels in all chemical compositions. The present results showed considerable variation in the mineral content of milk from different species. The levels of calcium and phosphorus are higher in sheep than in goat and camel milk. Compared to small ruminants, milk from camels is the richest in Na and K. Additionally, more calcium is present in the milk of camels than that of goats. Goat milk, the lowest in Ca and Na, contains more P than camel milk and more K than sheep's milk on average. The poorest microbial quality was that of camel milk for all bacterial counts. Based on TMAB, TCC, and *E. coli* counts, the microbiological quality of goat milk was higher than that of ovine milk, while ovine milk had better quality based on LAB, Y/M, and *S. aureus* values. For *Escherichia coli* and *Staphylococcus aureus*, there were no significant variations between the species studied. Results showed that all milk samples studied were completely free of two dangerous pathogens, *Salmonella* and sulfite-reducing *Clostridium*. The bacteriological quality of small ruminant's milk was acceptable and met the regulatory limits set by Tunisian dairy legislation. Regarding camel milk, the microbial analysis revealed poor quality that exceeds standard criteria.

Introduction

Cattle milk, which dominates national and international milk production, is the most widely consumed type in Tunisia. Furthermore, in some parts of the country and in specific contexts, milk from other animal species forms a major part of milk consumption. Possibilities for non-bovine milk production and manufacturing products have increased recently as the number of dairy cattle is perceived to have attained its upper ceiling from an environmental standpoint (Roy et al. 2020) and due to quantity (15% of the world milk production) as well as economic, cultural, and ecological factors (Rafik et al. 2016). Milk from other species is indeed considered to already have nutrient benefits over cattle milk. Recent research studies suggest that milk of camel, horse, donkey, sheep, and goat are quite better digestible, less allergenic, and more closer to human milk than bovine milk. Furthermore, milk from the aforementioned species can be valorized to produce decent specialized dairy products with nationally (local cultural) and internationally relevance, such as fermented milk, probiotic dairy drinks, yogurt, cheese, butter, ice cream, infant formulas, and milk tablets (Roy et al. 2020).

In the oases region of Tunisia, domestic genetic resources are composed mainly of goat, sheep, and one-humped camel species and consist mostly of indigenous breeds with 315150, 679204, and 50000 heads, respectively (DGEDA, 2018). The *Gharbi*, also known locally as "Bergui" or "Queue Fine de l'ouest (QFO)" is the most important sheep breed. The *Gharbi* breed is well adapted to the arid region and is traditionally managed under extensive production systems (Khaldi et al. 2020). The most common goat is the local population, which is distinguished by its large diversity and heterogeneity (Nafti et al. 2014), great resistance to pathogens, ability to adapt to harsh conditions (Ayeb et al. 2016), and is managed under an extensive pastoral system as well as a semi-intensive oasis system. Small ruminants species are dual-purpose animals that produce meat and milk for familial and local consumption (Vacca et al. 2009) or undergo transformation for local products (Leben, D'hen, Rayeb, etc.) (Gaddour et al. 2014).

The camel species, which is best suited to a harsh and difficult drought ecosystem, is entirely composed of the *Maghrebi* population. Animals are raised mainly within two management systems in the country's south: a conventional pastoral system and a semi-intensive system developed as a consequence of pasture depletion (Fguiri et al. 2018). Camels have long been utilized to generate meat (Chamekh et al. 2020) and milk for local use (Ayadi et al. 2009). Nevertheless, camel dairy production systems have rapidly intensified over recent decades in Tunisia's oasis region, with milk for human consumption being marketed throughout the country.

According to the literature, all mammals' milk contains similar basic components, but the amounts vary greatly between species (Roy et al. 2020). Due to the effect of genetic factors (both at the species and breed levels), physiological factors (e.g., lactation stage, milking interval, parity), nutritional factors (e.g., feed energy value and composition), and environmental conditions (e.g., location, season), milk composition can vary significantly even within the same species (Claeys et al. 2014).

In Tunisia, there is little data given on the characteristics of milk from mammalian species other than dairy cattle. Such research on the basic composition and microbial status of milk from goats, sheep, and one-humped camels reared in the western oasis region are limited. These species strengthen family nutrition, provide an income for the oases people, promote agricultural development, preserve local genetic resources, and enhance human nutrition in oases regions. The knowledge of differences in composition and quality of milk among species is necessary to provide information essential to the sustainable use and improvement of these underutilized local genetic resources. Therefore, the purpose of this study was to evaluate and compare the physical properties, chemical characteristics, mineral concentrations, and bacteriological quality of milk from local goat, *Gharbi* sheep, and *Maghrebi* camel in Tunisia's continental oasis region.

Materials And Methods

2.1 Animals and management conditions

This study was conducted between 2018 and 2019 in the continental oases regions of the southwest of Tunisia. This area belongs to the Saharan domain, which is characterized by an arid to hyper-arid bioclimatic stage. The precipitation is infrequent and irregular, with an annual total rainfall of less than 100 mm. The region's pronounced continentality is reflected in a highly contrasting thermal regime with large annual and diurnal amplitudes. The average temperature is around 22 °C, with extremely high summer temperatures (a maximum of 55 °C in July). Animals from private farms, including the *Gharbi* sheep breed (N = 100), the local goat population (N = 229), and the *Maghrebi* camel breed (N = 49), were enrolled in the study. Before sample collection, basic data on the animals (health status, age, calving season, lactation stage, parity number, etc.) was collected from the breeders. Healthy multiparous small ruminant animals with similar body conditions, aged 4 years, at the 3rd lactation, and the mid-lactation stage were selected for this study. Healthy camels with an average age of 9.5 ± 3.6 years, variable parities, and at the mid-lactation stage (the second and third months of lactation) were likewise used in this study.

Managed under a traditional feeding system, the *Gharbi* sheep and local goats grazed during the daytime for 6-7 hours on natural pasture in the oases' vicinity. In the middle of the day, animals were given 300-400 gd⁻¹ supplementation based on barley, wheat bran throughout the year, and waste dates during the period from October to June. During the confinement in the evening, the animals received alfalfa (*Medicago sativa*). The chemical composition of barley, wheat bran, dates, and alfalfa were [DM: 91%; CP: 12.7%; NDF: 26.3%; Ash: 3.9%; Net energy content: 1817.01 kcal. kg⁻¹ DM], [DM: 86.92%; CP: 14.9%; NDF: 37.7%; Ash: 4.1%; Net energy content: 1624.97 Kcal. kg⁻¹ DM], [DM: 88.56%; CP: 3.11%; NDF: 17.81%; Ash: 2.69%; Net energy content: 1931.42 Kcal. kg⁻¹ DM], [DM: 28.66%; CP: 19.22%; NDF: 45.3%; Ash: 14.20%; Net energy content: 1320 Kcal. kg⁻¹ DM], respectively. For both species, females were kept with their lambs or kids during the day and the evening containment period, except on days when milk samples were collected.

The selected camels were managed within a traditional system in which herds grazed on natural desert pastures dominated by halophilic species around chotts and non-halophilic plants including *Haloxylon salicornicum*, *Anabasis articulata*, *Atriplex mollis*, *Atriplex halimus*, *Retama Raetam*, *Haloxylan schmittianum*, *Panicum turgidum*, *Traganum nudatum*, *Calligonum*

comosum, *Calligonum azel*, *Aristida Pungens*, *Limoniastrum guyonianum*, *Stipagrostis pungen*, *Zygophyllum album*, *Sueda fructosa*, *Tamarix aphylla*, *Tamarix articulata*, *Tamarix gallica*, *Rhus tripartitum*, *Ephedra alata*. During times of shortage, animals were supplemented with barley, wheat bran across the year, and dates from October to June when wasted dates were available. All feedstuffs were distributed to all animals, regardless of their physiological stage.

2.2 Samples collection

Milk samples from 378 animals were obtained in the early morning after complete milking. A duplicate individual milk sample of 300 mL from each animal has been collected aseptically in clean, dry, and sterile tubes and kept at a temperature of 4 °C during sampling and transportation to the laboratory. The samples were delivered to the regional public health laboratory of Tozeur for microbiological analysis and the animal production laboratory (CRRAO) for physicochemical and mineral analysis.

2.3 Physical and chemical analysis

A Consort C933 pH meter was used to measure the pH at 20°C. A Gerber thermolacto-densimeter was used to determine raw milk density, and measurements were taken at 20°C. Dornic acidity was established using the AOAC-recommended titrimetric method (AOAC, 2000). All physical parameters were determined on the same sampling day. The milk samples were analyzed for lactose and ash using the official international analytical methods AOAC (2005) and AOAC (2012), respectively. Fat (IDF, 2009), dry matter (IDF, 2010), and total protein (IDF, 2014) were determined according to the IDF standard methods. The casein content was obtained by the difference between total nitrogen and non-casein nitrogen using the Kjeldahl method (IDF, 2004). The casein/protein ratio was calculated to determine the cheese value of the milk under consideration.

2.4 Mineral analysis

Minerals including calcium, sodium, potassium, and phosphorus were measured in milk samples. Calcium was measured using an atomic absorption spectrophotometer (Analytikjena: nova 400) following IDF (2007). As per AOAC standards (1984), Jenway flame emission spectroscopy was used to determine sodium and potassium in accordance with AOAC standards. To quantify the phosphorus in the milk sample, the colorimetric method incorporating the PhosphoVanado Molybdate complex (GB, 2010) was applied.

2.5 Microbiological analysis

Total mesophilic aerobic bacteria (TMAB), total coliform count (TCC), lactic acid bacteria (LAB), sulfite-reducing *Clostridium* (CSR), yeast and molds (Y/M), *Staphylococcus aureus* (*S. aureus*), *Escherichia coli* (*E. coli*), and *Salmonella* were all counted in the samples.

After thoroughly mixing the fresh milk samples, 1 mL was diluted with 9 mL of peptone water for microbiological analysis. Additional decimal dilutions were drawn up from this dilution (ISO, 2001a) and deposited on suitable media. According to ISO standards, TMAB (ISO, 2013), TCC (ISO, 2006), LAB (ISO, 1998), CSR (ISO, 2003a), Y/M (ISO, 2004), *S. aureus* (ISO, 2003b), *E. coli* (ISO, 2001b), and *Salmonella* (ISO, 2009) were conducted on duplicate samples, with the results averaged, and the microorganism count was expressed as a colony-forming unit. Before performing statistical analysis, the microbial counts were log₁₀-transformed to normalize the distributions.

2.6 Statistical analysis

Statistical analysis was performed by comparing the averages of different parameters between species being studied. The significant differences between means were determined by one-way analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS software (2004). The difference between the three species was determined by comparing the least-square means with adjusting the P values for multiple comparisons using the Tukey–Kramer test.

Results

The physical features of the milk samples presented in Table (1) indicated a significant difference among the three species ($P < 0.001$). Compared to goat's and camel's milk, sheep's milk showed higher dornic acidity and density ($P < 0.001$). The results revealed that the highest pH was obtained equally ($P > 0.05$) for ovine and camel species, followed by goat species, which presented the lowest pH ($P < 0.001$). The highest dornic acidity was observed in milk from sheep, followed by camels and then goat species ($P < 0.001$). Sheep breed produced the densest milk ($P < 0.001$), and the least dense milk was from goats and *Maghrebi* camels, which did not differ significantly ($P > 0.05$).

Table 1. Physical characteristics (mean $\pm$ standard deviation) of sheep, goats, and camel's milk in the Tunisian oasis region.

Species	Traits		
	pH	Density	Acidity ($^{\circ}$ D)
<i>Gharbi</i> sheep	6.61 $\pm$ 0.08 ^a	1032.98 $\pm$ 3.11 ^a	20.61 $\pm$ 3.23 ^a
Local goat	6.54 $\pm$ 0.09 ^b	1031.05 $\pm$ 2.82 ^b	15.96 $\pm$ 2.09 ^c
<i>Maghrebi</i> camel	6.63 $\pm$ 0.22 ^a	1030.63 $\pm$ 2.54 ^b	19.11 $\pm$ 4.08 ^b

a, b, c values with different superscripts within the same column are significantly ($p < 0.001$) different.

The content of dry matter, fat, protein, casein, lactose, ash, and the casein-protein ratio of milk from sheep, goat, and camel species were significantly different ($P < 0.001$) (Table 2). Sheep's milk had the highest ($P < 0.001$) dry matter, fat, protein, casein, lactose, and ash content. The local caprine population is the second-largest of all the components of the study. Finally, the camel population recorded the lowest values for the chemical constituents under study.

Although ovine species were superior in terms of casein and nitrogen content, the casein-protein ratio was higher ($P < 0.001$) among goat species (0.80), followed by sheep breeds (0.77) and the last camel population (0.74).

Table 2. Average chemical composition (mean $\pm$ standard deviation) of sheep, goat, and camel's milk in the Tunisian oasis area

Species	Traits (g/L)						
	Dry matter	Fat	Protein	Casein	Lactose	Ash	Casein/Protein
<i>Gharbi</i> sheep	204.13 $\pm$ 29.87 ^a	59.59 $\pm$ 3.98 ^a	55.33 $\pm$ 4.17 ^a	42.67 $\pm$ 3.22 ^a	44.25 $\pm$ 6.47 ^a	10.76 $\pm$ 1.43 ^a	0.77 $\pm$ 0.26 ^b
Local goat	132.94 $\pm$ 23.98 ^b	40.45 $\pm$ 6.24 ^b	35.43 $\pm$ 6.05 ^b	28.58 $\pm$ 4.76 ^b	40.48 $\pm$ 5.44 ^b	7.93 $\pm$ 1.64 ^b	0.80 $\pm$ 0.1 ^a
<i>Maghrebi</i> camel	115.24 $\pm$ 15.67 ^c	32.84 $\pm$ 4.88 ^c	30.97 $\pm$ 6.40 ^c	22.77 $\pm$ 4.27 ^c	37.21 $\pm$ 4.64 ^c	6.87 $\pm$ 1.59 ^c	0.74 $\pm$ 0.07 ^c

a, b, c, d values with different superscripts within the same column are significantly ($p < 0.001$) different.

As Table 3 illustrates, there were significant differences ($P < 0.001$) between the studied species in calcium, phosphorus, sodium, and potassium concentrations. The results demonstrated that milk produced by ewes contained the greatest levels of calcium and phosphorus ($P < 0.001$). Compared to the goat species in terms of calcium and phosphorus, camel milk was richer in calcium ($P < 0.001$), while goat's milk contained more phosphorus ($P < 0.001$). In contrast, for the other major

minerals, Negga milk was found to be richer in sodium and potassium ($P < 0.001$) than small ruminants. Ewes displayed milk with more sodium concentration and less potassium than goats ($P < 0.001$).

Table 3. Mineral concentrations (mean $\pm$ standard deviation) of small ruminants and camel's milk in the Tunisian oasis area.

Species	Minerals (g/L)			
	Ca	P	Na	K
<i>Gharbi</i> sheep	2.02 $\pm$ 0.27 ^a	1.45 $\pm$ 0.19 ^a	0.40 $\pm$ 0.05 ^b	1.30 $\pm$ 0.17 ^c
Local goat	1.40 $\pm$ 0.29 ^c	1.18 $\pm$ 0.24 ^b	0.28 $\pm$ 0.08 ^c	1.49 $\pm$ 0.30 ^b
<i>Maghrebi</i> camel	1.60 $\pm$ 0.17 ^b	0.58 $\pm$ 0.18 ^c	0.50 $\pm$ 0.13 ^a	1.81 $\pm$ 0.33 ^a

a, b, c, d values with different superscripts within the same column are significantly ($p < 0.001$) different.

The bacterial quality of the various types of milk is given in Table 4. As stated in the results, goat milk had higher microbial quality ($P < 0.001$) than sheep and camel milk based on TMAB, TCC, and *E. coli* counts. Ovine milk was of higher quality in terms of LAB, Y/M, and *S. aureus* values ($P < 0.001$). For all microbial counts, camel milk had the lowest microbiological quality.

The total mesophilic aerobic bacteria (TMAB) and *Escherichia coli* counts in the *Maghrebi* camel were significantly higher ($P < 0.001$) than those in the *Gharbi* sheep and local goats. By referring to total coliform (TCC) and *S. aureus* counts, camels still recorded higher levels of contamination ($P < 0.001$) than those of sheep and goat species, which did not differ significantly ($P > 0.05$).

The lactic acid bacteria (LAB) and molds and yeasts (Y/M) values reported in this study for each species were higher in camel's milk than in goats' and *Gharbi* sheep's milk at a very significant level ($P < 0.001$).

The three species analyzed were significantly different ($P < 0.001$) from each other for the average molds and yeasts (Y/M) and lactic acid bacteria (LAB) values. Levels of contamination were higher in camel's milk than in goat or *Gharbi* sheep. Clostridium Sulfite Reducer (CSR) and *Salmonella* were absent in all samples studied.

Table 4. Microbial loads ($\log_{10}$ CFU/mL) in the milk of studied species from the Tunisian oasis region.

Species	Microbial Flora							
	TMAB	TCC	LAB	CSR	Y/M	<i>S. aureus</i>	<i>E. coli</i>	<i>Salmonella</i>
<i>Gharbi</i> sheep	5.44 $\pm$ 0.31 ^b	3.24 $\pm$ 0.30 ^b	3.03 $\pm$ 0.31 ^c	0	3.19 $\pm$ 0.06 ^c	0.40 $\pm$ 0.77 ^b	0.43 $\pm$ 1.01 ^b	0
Local goat	5.17 $\pm$ 0.31 ^c	3.20 $\pm$ 0.31 ^b	3.44 $\pm$ 0.32 ^b	0	3.66 $\pm$ 0.21 ^b	0.47 $\pm$ 0.79 ^b	0.25 $\pm$ 0.83 ^c	0
<i>Maghrebi</i> camel	6.54 $\pm$ 0.35 ^a	5.16 $\pm$ 1.49 ^a	3.77 $\pm$ 0.65 ^a	0	4.22 $\pm$ 1.06 ^a	1.66 $\pm$ 1.63 ^a	2.64 $\pm$ 0.85 ^a	0

a, b, c, d values with different superscripts within the same column are significantly ($p < 0.001$) different.

TMAB: Total mesophilic aerobic bacteria; TCC: Total coliform count; LAB: Lactic acid bacteria; CSR: Sulfite-reducing Clostridium; Y/M: Yeast and molds; S. aureus: Staphylococcus aureus; E. coli: Escherichia coli.

Discussion

4.1 Milk chemical composition

A moderate to large variability in the composition of sheep, goats, and camel milk has been found in the literature (Park et al. 2007; Rouissi et al. 2008; Chamekh et al. 2020; Hilali et al. 2011; Kondily et al. 2012; Claeys et al. 2014; Monteiro et al. 2019). Despite the fact that many factors, such as individuals, parity, season, diet, management, environmental factors, locality, lactation stage, and udder health status, may have a significant impact on the major and minor components of milk (Park et al. 2007), the special variation engendered by genetics often significantly contributes (Yasmin et al. 2020). Our results showed significant heterogeneity in milk content across all species. With the exception of the casein-protein ratio, which favors goat species, the analysis indicates that sheep species were clearly superior to the populations of goats and camels in all chemical contents investigated, particularly at the levels of dry matter, fat, protein, casein, and ash contents. According to numerous researches, sheep's milk has the highest average value of the above ingredients than goats (Park et al. 2007; Kondily et al. 2012) and camel's milk (Claeys et al. 2014; Yasmin et al. 2020). Similarly, various authors have reported on the ancestry of goats in relation to camel species in the above chemical contents (Legesse et al. 2017; Yasmin et al. 2020).

Total solids, fat, protein, casein, and ash content in milk from native *Gharbi* were similar to those described by El Gharbi et al. (2015) for Tunisian Barbarin sheep breeds raised in a semiarid climate, but lower than those observed for Sicilo-Sarde and Comisane dairy sheep breeds (Rouissi et al. 2008; Aloulou et al. 2018) reared under an intensive system in the north of Tunisia. Our results are higher for all chemical constituents except fat content, which was lower when compared to the results of the oases D'man breed kept in an intensive system in south-eastern Tunisia (Dhaoui et al. 2019). The variation in the reported findings could be linked mainly to differences in the genetic potential of the breeds and management factors, including feeding and environmental factors.

The major carbohydrate lactose of ovine milk in this study was higher than most of the reported results for Tunisian Barabrin, Sicilo-Sarde, and Comisane sheep breeds (Rouissi et al. 2008; El Gharbi et al. 2015; Aloulou et al. 2018). However, lactose content was in line with the finding of Dhaoui et al. (2019) for the D'man breed.

The current result implies that the relatively high concentrations of dry matter, fat, protein, and other nutritive components are relevant characteristics of Tunisian sheep's milk. It is generally accepted that milk from breeds with low potential milking yields from the Mediterranean and tropical areas has a higher concentration of total solids, fat, and protein than the high-productive breeds from temperate regions (Hernandez-Castellano et al. 2019).

Goat milk results are consistent with local Tunisian goats (Ayeb et al. 2016), native Greek breeds (Kondily et al. 2012), and Algeria-Arabia (Hamidi et al. 2020). Higher levels were found in the Ethiopian goat breeds Buren and Arsi-Bale (Mestawet et al. 2012) and in the goat breeds Murciana-Granadina, Buren, and La Mancha (Ferro et al. 2017). The genotype potential, production system, environmental factors, and the stage of lactation at which samples were gathered could all explain the variation of current results from diverse literature sources (Currò et al. 2019).

The chemical components of camel milk studied were lower than those of Ayadi et al. (2009); however, they were nearly identical to those cited by Hamed et al. (2012) and Jemmali et al. (2016) and higher than Chamekh et al. (2020) with the exception of ash, which is higher than that in our study. The difference in results might be mostly ascribed to the variations in the feeding system and environmental conditions. Current Tunisian results were in accordance with those of the Egyptian *Maghrebi* camel (Abdalla et al. 2015) and the native Turkish breed (Karaman et al. 2021). Al Haj and Al Kanhal (2010) found that Ethiopian and Saudi camels had lower levels of content. The discrepancies in results from different existing literature could be attributed to the breeds, region, lactation stage at which samples were collected, and management conditions, including environmental factors and diet (Chamekh et al. 2020).

The casein-protein ratio with the largest value was found in goat milk (0.80), followed by sheep (0.77), and the smallest was found in camel milk (0.74). Similarly, the results for the casein-protein ratio are in line with other investigations in goats (Vacca et al. 2018) and sheep breeds (Rafik et al. 2016). The current results approached those cited in other camel breeds (Farah, 1993), whereas the same *Maghrebi* breed in a different region (Tunisia's south and center) provided lower casein to protein ratio (Attia et al. 2000; Hamed et al. 2012). The casein assay implied that goat milk had the lowest whey protein concentration and camel milk had the highest (Hilali et al. 2011). Increases in whey protein have technological impacts, including weaker curd texture and lower cheese yield (Barlowska et al. 2020). Protein content and casein content are critical elements in dairy product quality, as lower protein and casein content leads to reduced technical manufacturing properties of dairy products (Hilali et al. 2011). Otherwise, a reduced casein-to-whey-protein ratio (i.e., a higher proportion of whey proteins) has been proven to be better beneficial for rapid digestion process of milk proteins in infant formula than a casein-dominant protein composition (Roy et al. 2020), which is the fact of camel milk, which has just been recognized to have a whey protein composition that is extremely comparable to human milk (El-Hatmi et al. 2015) and it is indeed a perfect substitute for cattle milk in infant formulas preparation (Mudgil et al. 2022).

4.2 Physical parameters

Milk from sheep breeds had a higher average of all physical parameters (pH, density, and dornic acidity) than milk from goat species. Sheep population produced milk with a similar pH to camel population, but with a higher density and acidity content. The pH and acidity were higher in neggas than in goat species, while density was equivalent in both.

Several previous reports on the physical characteristics of sheep, goat, and camel milk were consistent with the findings of the present study (Park et al. 2007; Ayeb et al. 2016; Al Haj and Al Kanhal, 2010) and were distinct from other studies (Hilali et al. 2011; Kondily et al. 2012; Ismaili et al. 2019). Both pH and acidity levels of milk are indicative of animal health and milk hygienic quality. However, the pH value of milk in healthy animals should be 6.5 - 6.8 (Park et al. 2007) for small ruminants and 6.4 - 6.7 for camels (Singh et al. 2017). Bacterial activity may generate a lower pH in fresh milk, while higher pH readings suggest udder infection or mastitis (Carloni et al. 2016). The pH of milk is one of the most critical factors in the production of a variety of dairy products. It regulates the conformation of proteins, the activity of enzymes, and the dissociation of acids found in milk (Rafik et al. 2016).

High acidity suggests a high bacterial load and, as a result, the expansion of lactic microbiota, which is directly, impacted by the joint effect of temperature and storage conditions (Ismaili et al. 2019). Titratable acidity, like pH, provides information on the total dryness and freshness of the milk, making it an important factor when establishing the quality.

The composition and animal species of milk are commonly known to influence its physical qualities (Park et al., 2007; Hilali et al. 2011). As previously stated by other authors, the fat content associated with total solids in milk has a significant impact on its density (Park et al. 2007). Parmar et al. (2020) stated that the composition of milk influences physical properties such as density and, as a result, the basis for weight-volume calculations in the milk industry. Milk density changes are inextricably linked to its fat-free solids and fat content. The milk's high fat content corresponds to a lower density, and inversely. Variations in density can be related to a number of factors, involving lactation stage, climatic conditions, feeding behavior during the study period, housing conditions, genetic group, and analytical method, among others (Parmar et al. 2020).

4.3 Mineral content

The current results revealed significant differences in the mineral levels of milk from the three species. The concentrations of Ca and P are higher in sheep than in goat and camel milk. Compared to small ruminants, milk from the camel is the richest in Na and K. Additionally, more Ca is present in milk from camels than in goats. Goat milk, the poorest type of milk in Ca and Na, contains on average more P than camel milk and more K than sheep's milk.

Our results are consistent with those previously published for ovine (Hilali et al. 2011) and caprine (Monteiro et al. 2019) species. The present study revealed that sheep's milk had higher concentrations of Ca, P, and Na and lower K levels than goat's milk. K levels in sheep milk were shown to be greater in other experiments (AL-Wabel, 2008). Hilali et al. (2011) pointed out

that sheep have higher Ca, P, and Na levels and lower K levels than goats. Similarly, Monteiro et al. (2019) stated that sheep's milk contains the most calcium and phosphorus, whereas goat milk contains the greatest potassium concentration.

The phosphorus concentration of *Maghrebi* camel milk raised in Tunisian oasis was found to be lower than that found by Faye et al. (2008) but comparable to that cited by Konuspayeva et al. (2010) and Singh et al. (2017). Referring to the potassium result, a high concentration was observed, which is in agreement with other findings (Singh et al. 2017).

The salty flavor Camel milk contains a high concentration of minerals, particularly Ca and K (Benmeziiane-Derradji, 2021), as a result of the salt-rich pastoral plants consumed. According to Benmeziiane-Derradji (2021), camel species have greatly higher concentrations of Na and K than small ruminants, which agrees with the results of our study. Nonetheless, mineral content varies greatly depending on animal species (Clayes et al. 2014), breed differences (Al Haj and Al Kanhal 2010), individual animals, stage of lactation, udder health status (Stocco et al. 2019), production system (Singh et al. 2017), analytical procedures (Attia et al. 2000), water intake (Singh et al. 2017), and nutritional status and diet (Pietrzak-Fiećko and Kamelska-Sadowska 2020).

Low Na concentrations were obtained for all species, which is similar to previous works in camels (Benmeziiane-Derradji, 2021), goats (Currò et al. 2019), and sheep breeds (Khan et al. 2006) but in contrast with other studies, which reported higher levels in camels (Singh et al. 2017), goats (Stergiadis et al. 2019), and sheep species (Monteiro et al. 2019). This fluctuation could be explained by the lactation stage. In fact, the Na level in small ruminant milk is higher in the early stages of lactation than in the mid and late stages (Khan et al. 2006).

4.4 Bacteriological quality

According to TMAB, TCC, and *E. coli* counts, goat milk had a higher microbiological quality than sheep's and Negga's milk. In terms of LAB, Y/M, and *S. aureus* values, ovine milk is superior. Across all microbiological loads, the poor bacteriological quality was that of camel milk.

S. aureus and *E. coli* were common and found at various levels of contamination in all milk types. *Staphylococcus* in milk is generated by two main sources: the first is a lack of adequate hygienic practices and improper milking procedures (Fatima et al. 2013), and the second is mastitis, which affects animals (Benmeziiane-Derradji, 2021). Because the animals in this study were healthy and milked in a sanitary manner, the incidence of *Staphylococcus* in the milk samples could be associated with the development of asymptomatic mastitis (Alebie et al. 2021).

Except for *Maghrebi* animals, which produce milk with the greatest count, there were no statistically significant differences in TCC between the milk of the investigated species. Fatima et al. (2013) stated higher TMAB, TCC, LAB, Y/M, *S. aureus*, and *E. coli* levels in sheep milk. Tabet et al. (2016) observed increased loads in goats milk, while Kalhotka et al. (2015) found greater contamination rates for both species. Smaller overall microbial numbers were observed among goats (Abd El Aal and Awad 2008) and ewe's milk (Tonamo et al. 2020).

Camel milk, as stated in the results, contained a high level of FAMT. These findings are identical to those mentioned by Aduugna et al. (2013) and they are higher than the results of Abera et al. (2016) and Karaman et al. (2021). Ismaili et al. (2019) discovered FMAT loads exceeding $8 \log_{10}$ CFU/mL. In terms of TCC, our results approached those cited by Wasie et al. (2015) but lesser than those of Benkerroun et al. (2003), Benyagoub and Ayat (2015), and Ismaili et al. (2019).

At a low level, the mean of the lactic bacteria number was $3.77 \pm 0.65 \log_{10}$ CFU/mL, which is smaller than what Benkerroun et al. (2003) and Ismaili et al. (2019) reported. The elevated concentrations of lysozyme and ascorbic acid in camel milk, as stated earlier by other scientists, could explain the low level of lactic acid bacteria (Karaman et al. 2021). The Y/M count in *Negga's* milk found in the current study was $4.22 \pm 1.13 \log_{10}$ CFU/mL. The mean level is lower than that of Sudanese (Karaman et al. 2021) and Moroccan (Ismaili et al., 2019) camels. The reduced yeast and mold counts could be attributed to the natural milk pH, which promotes bacterial growth and reduces Y/M, as detected in the study's samples (Karaman et al.

2021). Fguiri et al. (2018) reported lower levels in studies conducted in Tunisia on the same camel breed and focused on counting the mesophilic bacteria, LAB, and coliforms.

High total bacterial counts in raw milk are primarily due to the unsanitary conditions, under which the milk was managed, as well as the storage temperature and time since milking, and also the health problems of milking animals (Adugna et al. 2013). With the current study, the main source of contamination could be attributed to the contamination of the camel udder by the hands of unhygienic milkers or unhygienic milking procedures. Microbes could be transmitted from the environment, such as excrement, bedding, and ground, by contaminated milk handling personnel's hands, clothing, and mouth (Alebie et al. 2021).

This study showed that all milk samples studied were completely free of two dangerous pathogens: *Salmonella* and sulfite-reducing *Clostridium*, which indicates that the two pathogens are rare in the milk of small ruminants and camels in sampled flocks. A comparable conclusion was attained for goat milk (Tabet et al. 2016), sheep milk (Fatima et al. 2013), and camel milk (Benyagoub and Ayat 2015).

A variety of factors, comprising breed (Tonamo et al. 2020), milking practice, lactation stage (Nagy et al. 2013; Fguiri et al. 2018), farm management (Abera et al. 2016), years and season (Kondily et al. 2012; Ismaili et al. 2019), housing conditions and feeding practices (Fguiri et al. 2018), animal health, flock size, cleanliness of the premises and milk handling, and storage equipment (Carloni et al. 2016) may influence and all contribute to the bacteriological quality of milk.

According to the findings of the current investigation, the levels of microbiological contamination of raw milk of goats and sheep in the studied area were acceptable. Microbiological analysis meets the requirements of Tunisian legislation on milk and dairy product quality (NT 14.141 (2004)). In contrast, the results revealed that the levels of bacterial loads of raw camel milk in the study area were inadequate and did not meet Tunisian legislation's standard specifications. The camel milk is commonly produced, conserved, and transported under unhygienic conditions. Because bacteria in milk can degrade milk components, reduce shelf life, and cause illnesses in humans, the bacteriological quality of raw milk should therefore be a key concern for farmers, processors, and the general public (Adugna et al. 2013).

Conclusion

The results highlight differences among the three milk types as well as the distinctive characteristics that distinguish each species. The Na and K concentrations marked the *Maghrebi* camel. In terms of density, dornic acidity, total solids, fat, protein, casein, ash, Ca, P, lactic bacteria, Yeast and molds, and *Staphylococcus aureus* counts, the *Gharbi* sheep breed produces the highest milk quality. Milk with decent casein to protein ratios, TMAB, TCC, and *Escherichia coli* counts is produced by the autochthonous goat population. When compared to standards encountered in the scientific literature, the assessment of small ruminants and camel milk reveals good physicochemical properties and remarkable mineral profiles. The microbiological quality of small ruminant's milk was acceptable and met the regulatory limits set by Tunisian dairy legislation. For camel milk, the microbial analysis revealed poor quality that exceeds the standards, requiring strict hygienic control along the value chain.

Based on the findings of this study, it could be concluded that there is a relatively high potential for high-quality milk for possible processing valuation in these neglected local genetic resources given proper management and improvement. Therefore, a management plan should be implemented for these underexploited species, guiding their characterization, conservation, and improvement, and should be premised on the objective of their successful introduction into a productive economy.

Declarations

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Conflicts of interest/Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

Authors' contributions

Zahran Khaldi was in charge of the study design, milk sample collection, physicochemical and mineral analysis, contributed to the bacteriological analysis, performed statistical analysis and interpretation of data, drafting the manuscript, and was a major contributor in writing the manuscript. The corresponding author is **Zahran Khaldi**.

Mounir Nafti participated in the study design, milk sample collection, physicochemical, and mineral analysis, microbiological analysis, data analysis, and interpretation, and manuscript writing.

Mohamed Tabarek Jilani participated in the study's design, conducted bacteriological analysis on milk samples, and assisted in data interpretation.

Zahran Khaldi written the first draft of the manuscript, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

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